R-Matrix analysis of $^{149}\text{Sm}$ using DICER and DANCE data

Th. Stamatopoulos$^1$, P. Koehler$^1$, A. Couture$^1$, G. Rusev$^2$, B. DiGiovine$^3$

1. Physics Division, Los Alamos National Laboratory, 87545, NM, USA
2. Chemistry Division, Los Alamos National Laboratory, 87545, NM, USA
3. Weapons Stockpile Modernization Division, Los Alamos National Laboratory, 87545, NM, USA
Introduction: Motivation

- According to a report by L. Leal (ORNL/TM-2005/065)

\[^{149}\text{Sm} \text{ capture rate underestimates measured capture rates for PWR experiments by 4.8%}\]

- Only a few data sets in EXFOR

- Resonance parameters do exist but better uncertainties and covariances are needed
Introduction: Summary

• We performed capture and transmission measurements with:
  – the DANCE (Detector for Advanced Neutron Capture Experiments) instrument
  – Capture data from 8 eV – 1 keV
  – and DICER (Device for Indirect Capture Experiments on Radionuclides) instruments
  – Transmission data from 1 meV – 1 keV

• Data analysis is complete

• R-Matrix analysis is complete

• Report with resonance parameters to be used in next evaluations:
  LA-UR-23-32571
  Combined study of n+^{149}Sm with DANCE and DICER at LANSCE
  A. Stamatopoulos, P. Koehler, E. Leal-Cidoncha

• Phys. Rev. C manuscript is being reviewed by co-authors
The Los Alamos Neutron Science Center - LANSCE

500-800 MeV protons

keV – MeV neutrons

meV – keV neutrons
The Los Alamos Neutron Science Center – LANSCE
Lujan Center – Low energy neutrons

DANCE \( (n,\gamma)(?) \)

Lujan Center

DICER \((n,\text{tot}), \("(n,\gamma)"\)\)
The DICER instrument

Rotating Beam Blocker

Binocular Collimator

Aperture Stop Collimator

Dual PMT Detectors
Experiments @ DICER

- nat\(^{Sm}\) experiments were performed prior, in order to:
  - Get experience with the target fabrication
  - Get experience with powdered samples at DICER
- ~5mg \(^{149}Sm\) thin sample
- ~12mg \(^{149}Sm\) thick sample
- 1 mm diameter
- 97.669% purity
- Powder stuffed in capillary tubes
- Capillary tubes inserted in Al canisters
Experiment @ DANCE

- DANCE to get the capture yields
- There metallic samples were used
  - 97.93% purity
  - 1, 3, and 10 mg
  - 1 cm in diameter
- DANCE also provides multiplicities
- Different multiplicity distributions for different spins
- DANCE is used as a spinometer

![Graphs showing multiplicity distributions for different spins and energy levels.](image-url)
R-Matrix analysis: Resonance parameters

- Fits in capture and transmission data using SAMMY

Resolved doublet @ 15 eV

Evaluated $\Gamma_n$ is too large
R-Matrix analysis: Resonance parameters

- 163 resonances were resolved, up to ~521 eV
- Uncertainties on $\Gamma_\gamma$: less than 13%, average uncertainty: ~3.5%
- Uncertainties on $\Gamma_n$: less than 18%, average uncertainty: ~3.8%

TABLE III: List of $^{149}$Sm resonance parameters obtained from the present work along with their uncertainties. In cases where the data were insensitive to the corresponding width, ENDF values were adopted. In those cases, the uncertainties are marked with a dash.

<table>
<thead>
<tr>
<th>En (eV)</th>
<th>$\delta$En</th>
<th>$\Gamma_\gamma$ (meV)</th>
<th>$\delta\Gamma_\gamma$ (%)</th>
<th>$\Gamma_n$ (meV)</th>
<th>$\delta\Gamma_n$ (%)</th>
<th>$\delta\Gamma_n$ (%)</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>-123.7000 0.9277</td>
<td>60 - -</td>
<td>2270 42.5</td>
<td>1.87</td>
<td>4</td>
<td></td>
<td></td>
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<td>-88.4600 0.6912</td>
<td>64.9 - -</td>
<td>6270 71.6</td>
<td>1.14</td>
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<tr>
<td>0.0970 0.0001</td>
<td>-65.62 -</td>
<td>0.545 0.000528</td>
<td>0.1</td>
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<td>0.8703 0.0001</td>
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<td>-0.749 0.000522</td>
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<td>1.67 0.00169</td>
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<td>56.31 1.55 2.75</td>
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<td>0.17</td>
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<tr>
<td>9.2017 0.0015</td>
<td>40.24 2.03 5.05</td>
<td>0.197 0.00422</td>
<td>2.14</td>
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<tr>
<td>12.0104 0.0001</td>
<td>67.58 0.32 0.47</td>
<td>1.74 0.00301</td>
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<tr>
<td>14.8669 0.001</td>
<td>57.12 1.78 3.12</td>
<td>1.45 0.0127</td>
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<tr>
<td>14.9166 0.0003</td>
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<td>3.96 0.0127</td>
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<tr>
<td>15.8713 0.0006</td>
<td>63.85 1.45 2.27</td>
<td>0.323 0.00172</td>
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<tr>
<td>17.1631 0.0002</td>
<td>64.54 0.46 0.71</td>
<td>1.85 0.00387</td>
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<td>23.2562 0.0005</td>
<td>97.55 1.33 1.36</td>
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<td>24.7428 0.0017</td>
<td>169.2 6.41 3.79</td>
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<td>1.48</td>
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</tbody>
</table>
Corrections

- Correction for missed resonances using Fuketa-Harvey method: Provides corrected number of resonances, strength functions ($S_0$) and level spacings ($D_0$).
- Similar corrections for various thresholds
Radiation widths

- Radiation widths seem to change distribution around 225 eV
Radiation widths

- Radiation widths seem to change distribution around 225 eV
- Kolmogorov-Smirnov (KS) test, which is sensitive to the tails, suggests they don’t (KS statistics = 0.027, p-value = 0.0003)
- Anderson-Darling (AD) test, which is sensitive to deviations in both the center and the tails of the distributions, suggests that they are statistically different (p-value = 0.363)
- q-q plot suggest that overall, they come from the same distribution with different parameters.
Neutron widths

- Neutron width Cumulative Distribution Functions (CDFs) seem to be statistically similar, as expected for different angular momenta.
- KS test: p-value of 0.735, suggests that the two CFDs are statistically similar.
- AD test: p-value of 0.361, suggests that the two CFDs are statistically similar.
- q-q plot does not question the KS and AD tests.
Neutron widths

- Neutron width Cumulative Distribution Functions (CDFs) seem to be statistically similar across the whole energy range of the present work.
- KS test: p-value of 0.782, suggests that the two CFDs are statistically similar
- AD test: p-value of 0.360, suggests that the two CFDs are statistically similar
- q-q plot does not question the KS and AD tests.
Our data indicate that:

- 38 spins are incorrectly assigned in the ENDF-VIII.0 and JEFF-3.3 evaluations
- 41 spins are incorrectly assigned in the JENDL-5 evaluation
- 58 new resonances were resolved
  - We resolved 215 resonances
  - Evaluations include 157 resonances
- Slight differences in the resonance energies
- Differences in resonance parameters up to 400%
Thank you for your attention!
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NOVEMBER 18 - 22, 2024
Resonance energies

- Linear fit
- $E^{1.5}$ fit

$E_{\text{exp}} - E_{\text{eval}}$ (eV)

$E_{\text{exp}}$ (eV)

Data from:
- ENDF/B-VIII.0
- JENDL-5